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AN EVALUATION OF WATER-IN-OIL EMULSIONS IN AN OIL-FIRED RESIDENTIAL HOT-WATER FURNACE

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by

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ABSTRACT

As part of a continuing program to evaluate energy conservation strategies applicable to residential heating systems, the Canadian Combustion Research Laboratory (CCRL) evaluated the performance of a domestic hot-water furnace when fired with various emulsions of water in No. 2 fuel oil. Experiments were conducted with both the standard cast-iron head burner and a retention-head burner known to give superior performance; each burner configuration was operated with No. 2 fuel oil emulsion containing from 0 to 20 volume % of water.

The use of fuel oil emulsions containing 1 to 2 volume % of water increased steady-state efficiency only marginally. Furnace efficiencies increased by about 1.1% with the cast-iron head burner and 0.2% with the retention-head burner. With emulsions containing more than 10 volume % water, the thermodynamic penalty associated with heating the water in the fuel to flue gas temperatures more than offset any potential gains in efficiency which migh have resulted from a very slight improvement in combustion performance.

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1. INTRODUCTION

In 1976 as part of the Energy Research Program of the Canada Centre for Mineral and Energy Technology (CANMET), the Canadian Combustion Research Laboratory (CCRL) began an evaluation of water-in-oil emulsions as an energy conservation strategy in residential heating. A typical hot-water boiler was selected to study changes in furnace efficiency due to the combustion of chemically stabilized, mechanically-produced emulsions of No. 2 fuel oil containing 0 to 20 volume % of water. For comparative purposes the original burner head was replaced by one of improved design which typically improves furnace efficiency by up to 10% when burning No. 2 fuel oil (1, 2).

2. TEST EQUIPMENT

2.1 Hot-water Furnace Specifications

The test furnace was an American Standard Model No. BN1340A equipped with a standard-head Anthes burner. It had a maximum rated output of 169,000 Btu/hr at a firing rate of 1.5 US gph; however, in the test program a firing rate of 1.0 US gph was selected which corresponds to an output of 112,000 Btu/hr. The same firing rate was used for the retention-head burner manufactured by Aero to maintain a steady load on the furnace, the thermostatic control was by-passed and the output hot water was cooled to 110 F by an air-cooled heat exchanger before being returned to the furnace.

2.2 Emulsified Fuel Supply

The No. 2 fuel oil used during the test program had a specific gravity of 0.85 and a calorific value of 19,600 Btu/lb.

Stable water-in-oil emusions containing up to 20 volume % water were produced in a 12 US gallon tank by continuously recirculating No. 2 fuel oil which had been previously blended with 4 volume % commercial emulsifier (Span 80, Atlas Chemical Co.) before the addition.

As an example, an emulsion containing 10 volume % water of remained stable for about twenty minutes without circulation or mixing. Without emulsifier the stability would be less than half a minute.

2.2 Emulsified Fuel Supply (cont'd)

As shown in Figure 1, the stability was reduced at lower water contents and increased at higher water contents until the emulsion changed phase at about 75 volume %.

The oil supply system was arranged so that either No. 2 fuel oil from a 300 US gallon supply tank or emulsion from the small tank could be fed to the burner. This was necessary for reference tests on No. 2 fuel oil and in case of ignition difficulties when using high water content emulsions.

Flow metering tests at 100 psig revealed that the flowrate increased by 8% with an emulsion containing 20 volume % water relative to No. 2 fuel oil through the same nozzle. However, due to the water content of the emulsion this represents a decrease in No. 2 fuel oil consumption of 13.6%.

2.3 Monitoring of Combustion Performance

Combustion performance was monitored by continuously measuring flue gas temperature and the O_2 and the CO_2 content of the flue gas; the smoke number was measured by a Bacharach smoke spot instrument at frequent intervals.

3. EXPERIMENTAL PROGRAM AND RESULTS

3.1 Test Program

The test program was planned to evaluate the potential of water-in-oil emulsions as a conservation strategy and to compare the combustion performance of emulsions with both a standard-head burner and a retention-head retrofit burner.

Sixteen steady-state tests were conducted on the furnace at incremental water contents ranging from 0 to 20 volume % in No. 2 fuel oil. During each test, complete profiles of combustion efficiency, flue gas temperature and Bacharach smoke number were obtained over the full available range of excess combustion air for both No. 2 fuel oil and the particular emulsion being evaluated. This procedure minimized the variations that are normally observed in furnace operations due to daily changes in external variables such as ambient temperature,

atmospheric pressure, instrument drift and calibration etc. Baseline tests were also conducted on the standard-head burner with No. 2 fuel oil only and on the retention-head burner using No. 2 fuel oil which had been blended with 4 volume % emulsifier, but no water. Figures 2 to 8 show the profiles obtained at each water-in-oil level with the cast-iron head. Figures 9 to 17 show similar data for the retention head.

It can be seen from an examination of the combustion performance profiles that there is variation between No. 2 fuel oil operation and emulsion operation for the same burner configuration. The maximum improvement in efficiency was 1.1% with the cast-iron head burner at 1.0 volume % water and 0.2% at 2.0 volume % water with the retention-head burner. These differences are not significant and are within the experimental scatter indicated by an examination of both the No. 2 fuel oil and the emulsion data summarized in Table 1. A gain in steady-state efficiency of about 5% can be obtained by changing to a retention-head burner; this improvement is far greater than can be obtained by adding water to the fuel of an inefficient burner.

4. CONCLUSIONS

The use of water-in-oil emulsions in steady-state performance tests on a residential hot-water furnace have shown negligible improvements in furnace efficiency. The maximum efficiency gain of 1.1% is within the experimental scatter associated with the sensitivity of the measuring system and is not considered significant. Operational difficulties associated with the use of emulsions occurred during the test program; these were pump failures, furnace corrosion, ignition difficulties and combustion instability, particularly with emulsions containing over 10 volume % water. Far greater improvements in furnace performance can be obtained using documented conservation strategies such as the retention-head burner rather than attempting to upgrade combustion efficiency by water addition.

5. REFERENCES

(1) Hayden, A.C.S., Braaten, R.W. and Brown, T.D., "Oil Conservation in Home Heating", ASME Winter Annual Meeting Paper No. 76WA/Fu8 (1976).

(2) Hayden, A.C.S., Braaten, R.W. and Brown, T.D. "Emissions and Energy Conservation in Residential Oil Heating" J.APCA 28, 7, pp 669-672 (1978).

TABLE 1

FURNACE EFFICIENCIES FOR COMBUSTION
OF WATER/OIL EMULSIONS IN
A RESIDENTIAL HOT-WATER FURNACE

Test No.	Burner Head	Water/Oil Emulsion		No. 2 Fuel Oil
		Water Content Vol %	Furnace Efficiency* %	Furnace Efficiency* %
1	Standard Cast Iron	0	-	79.1
2		1.0	79.5	78.4
3		2.0	-	-
4		3.0	80.0	79.7
5		5.0	78.3	78.3
6		7.0	79.7	79.3
7		10.0	80.5	80.5
8		15.0	76.9	78.6
9		20.0	78.2	79.0
10	Retention	0	85.4**	85.0**
11		1.0	85.2	85.6
12		2.0	86.2	86.0
13		3.0	85.3	85.1
14		5.0	85.1	85.0
15		7.0	85.2	85.2
16		10.0	85.3	85.4
17		15.0	85.1	85.7
18		20.0	85.0	85.5

*Excess air adjusted to give No. 1 Smoke Number.

**No. 2 fuel oil blended with 4 volume % emulsifier.

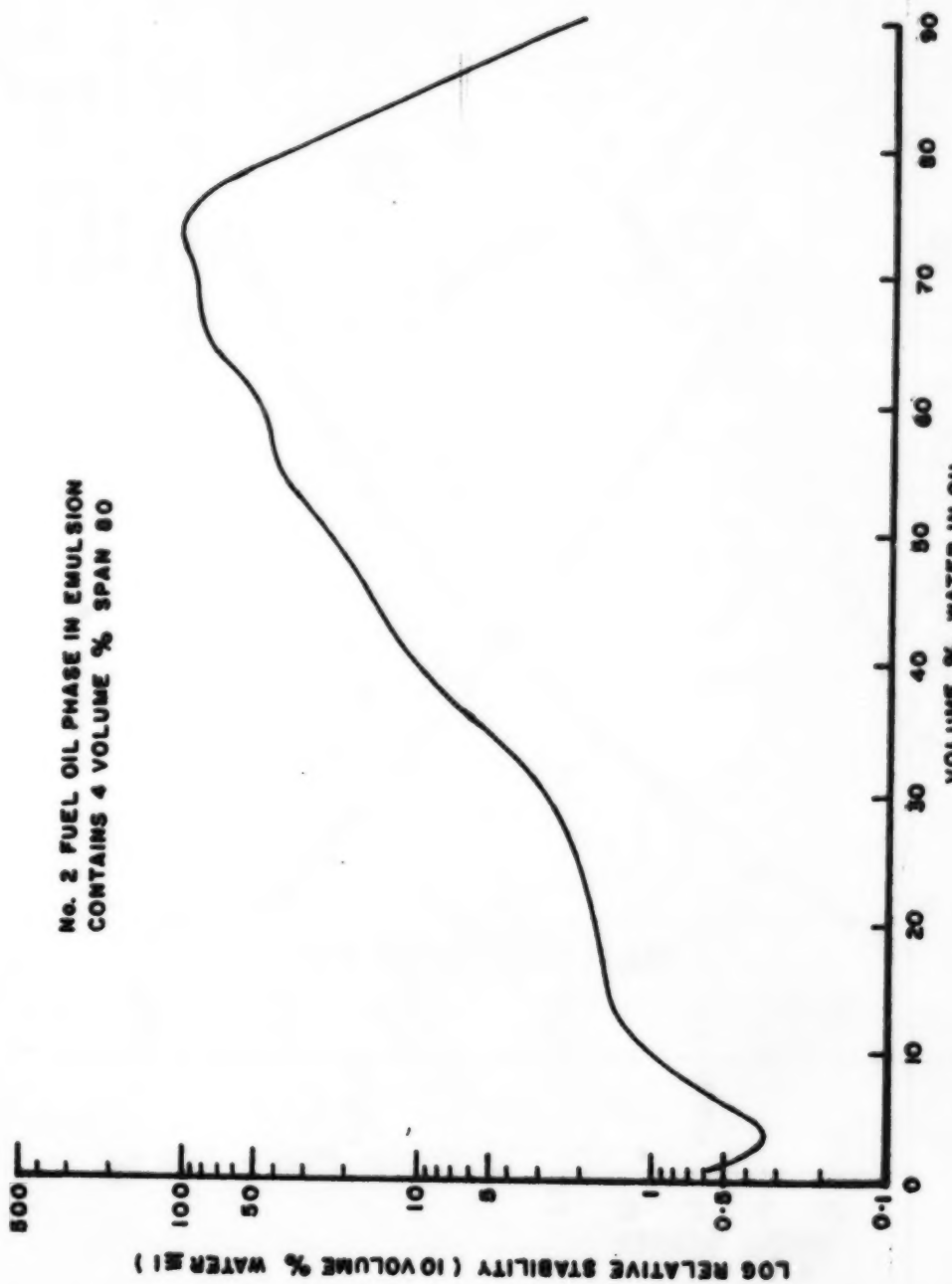

Figure 1. Relative Stability of Emulsions as a Function of Water Content

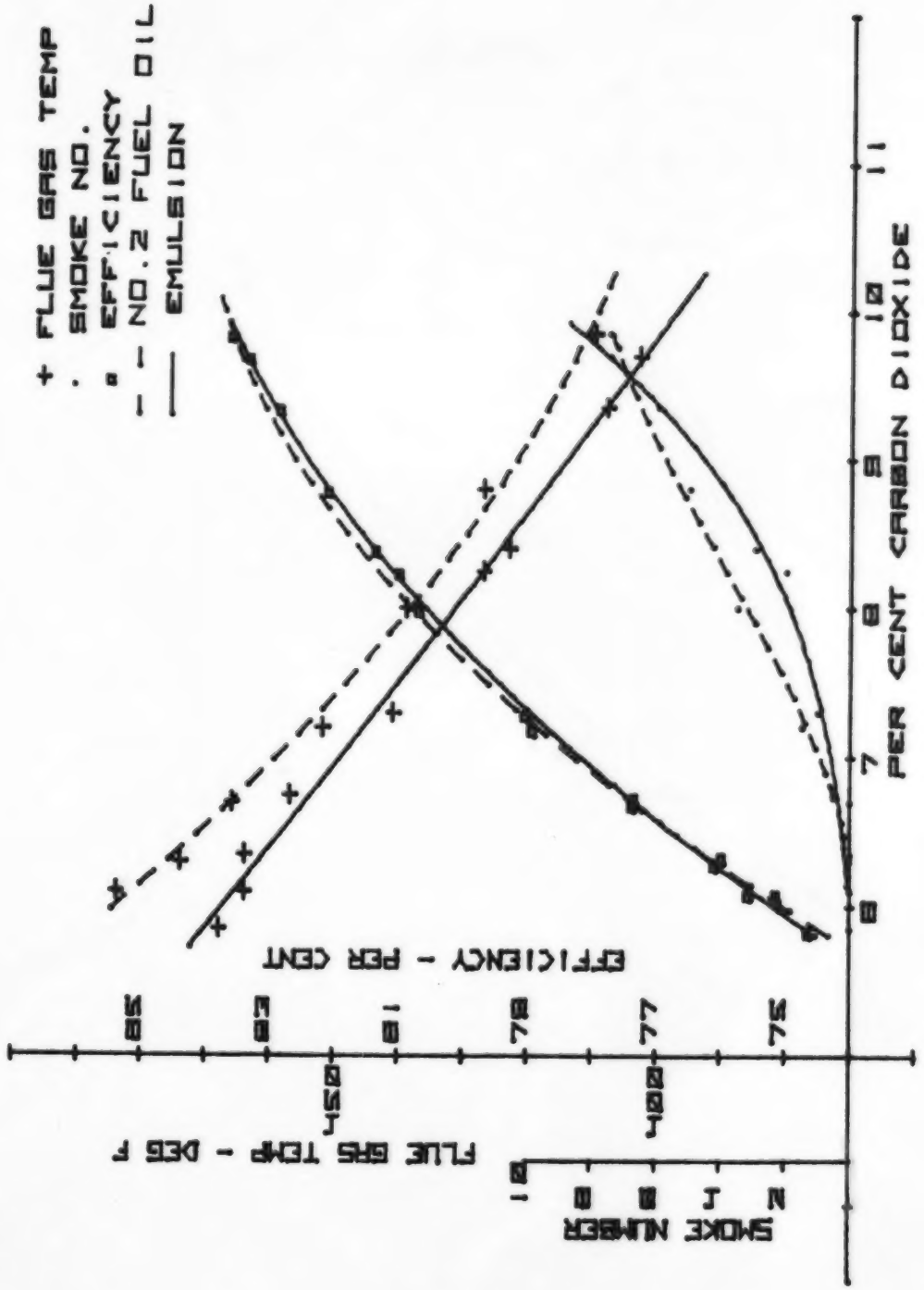

Figure 2. Combustion Performance Profiles with the Standard-Head Burner; Emulsion Water Content 1.0 vol %

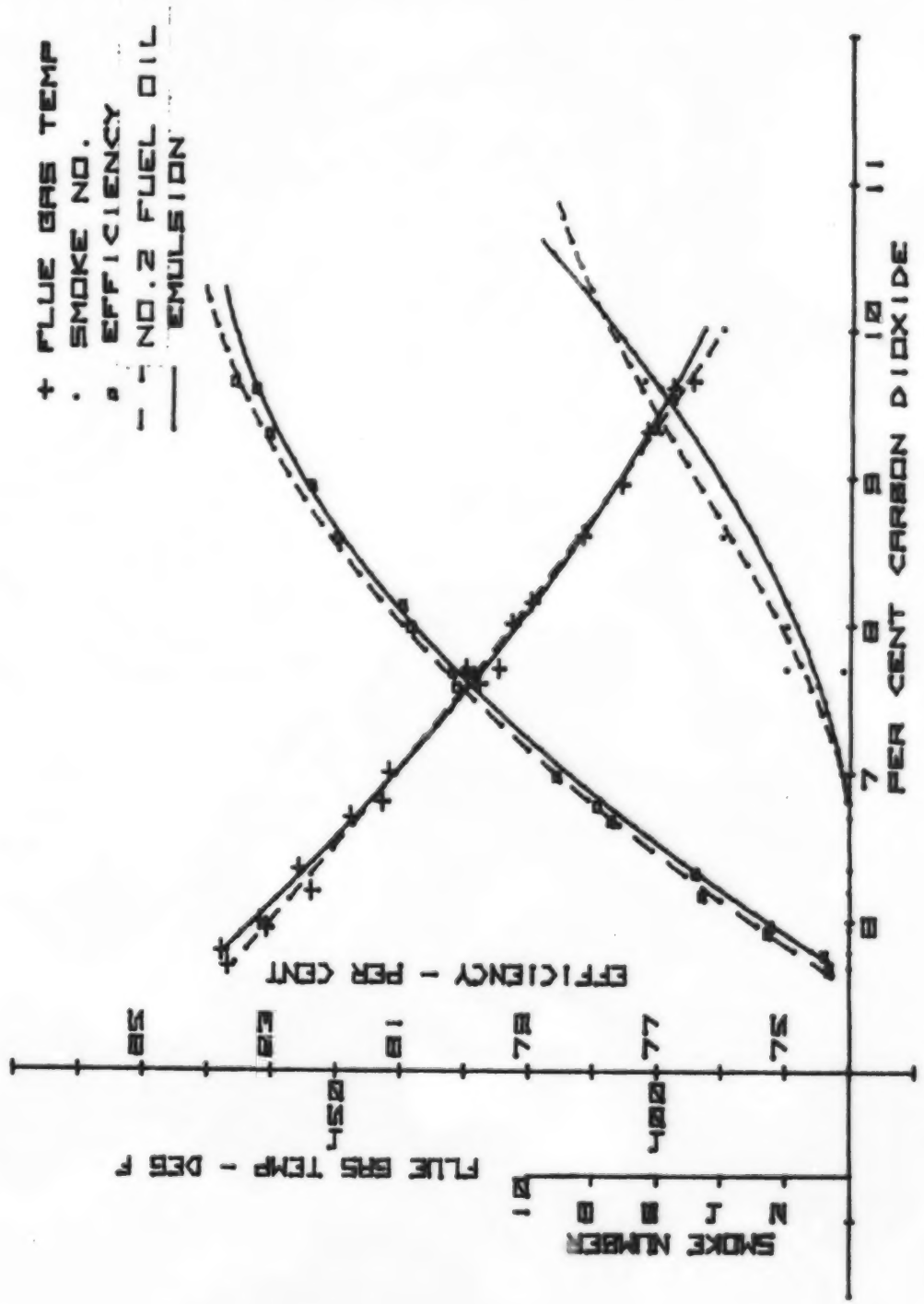

Figure 3. Combustion Performance Profiles Standard-Head Burner; Emulsion Water Content 3.0 vol %

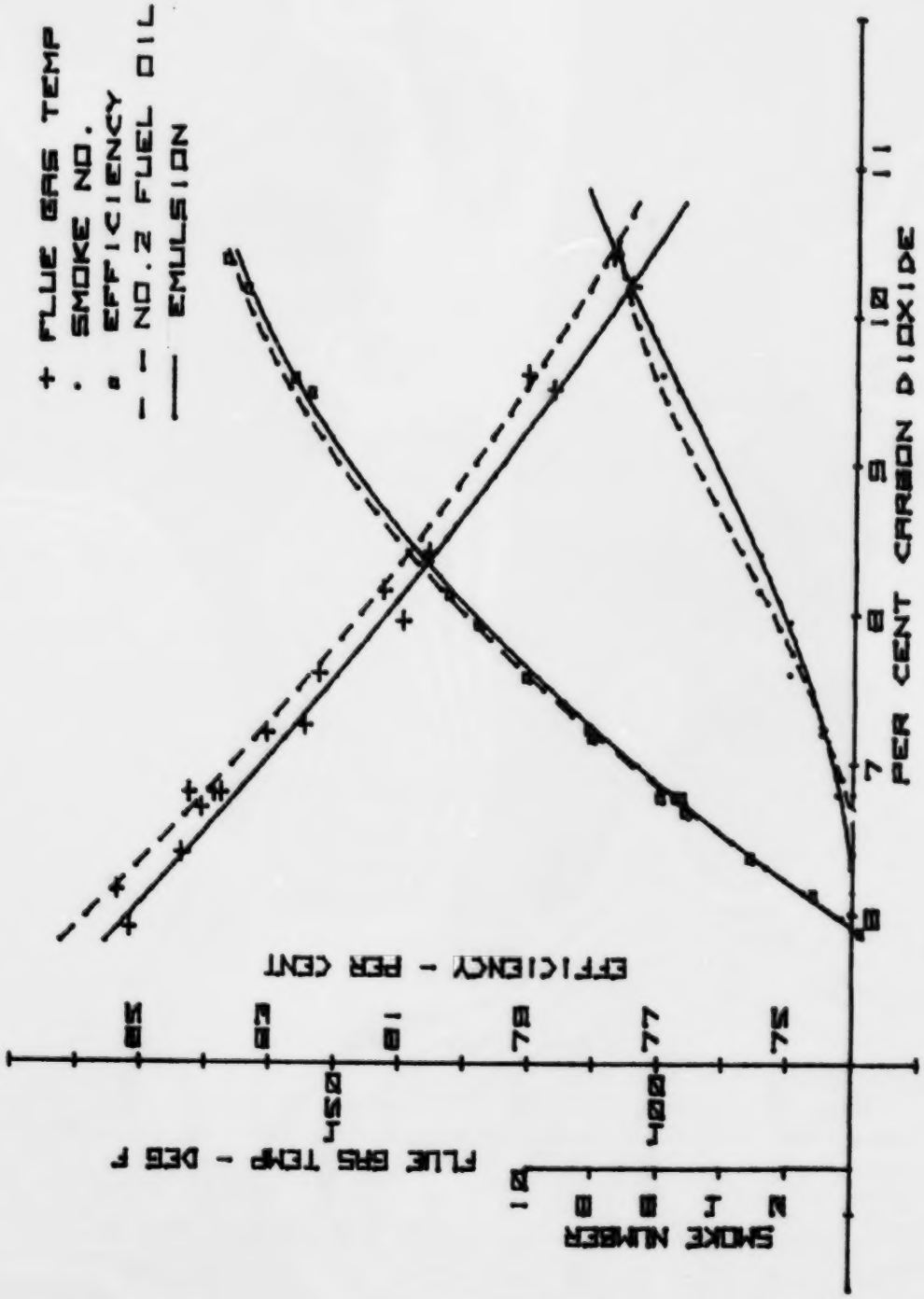

Figure 4. Combustion Performance Profiles with Standard-Head Burner; Emulsion Water Content 5.0 vol %

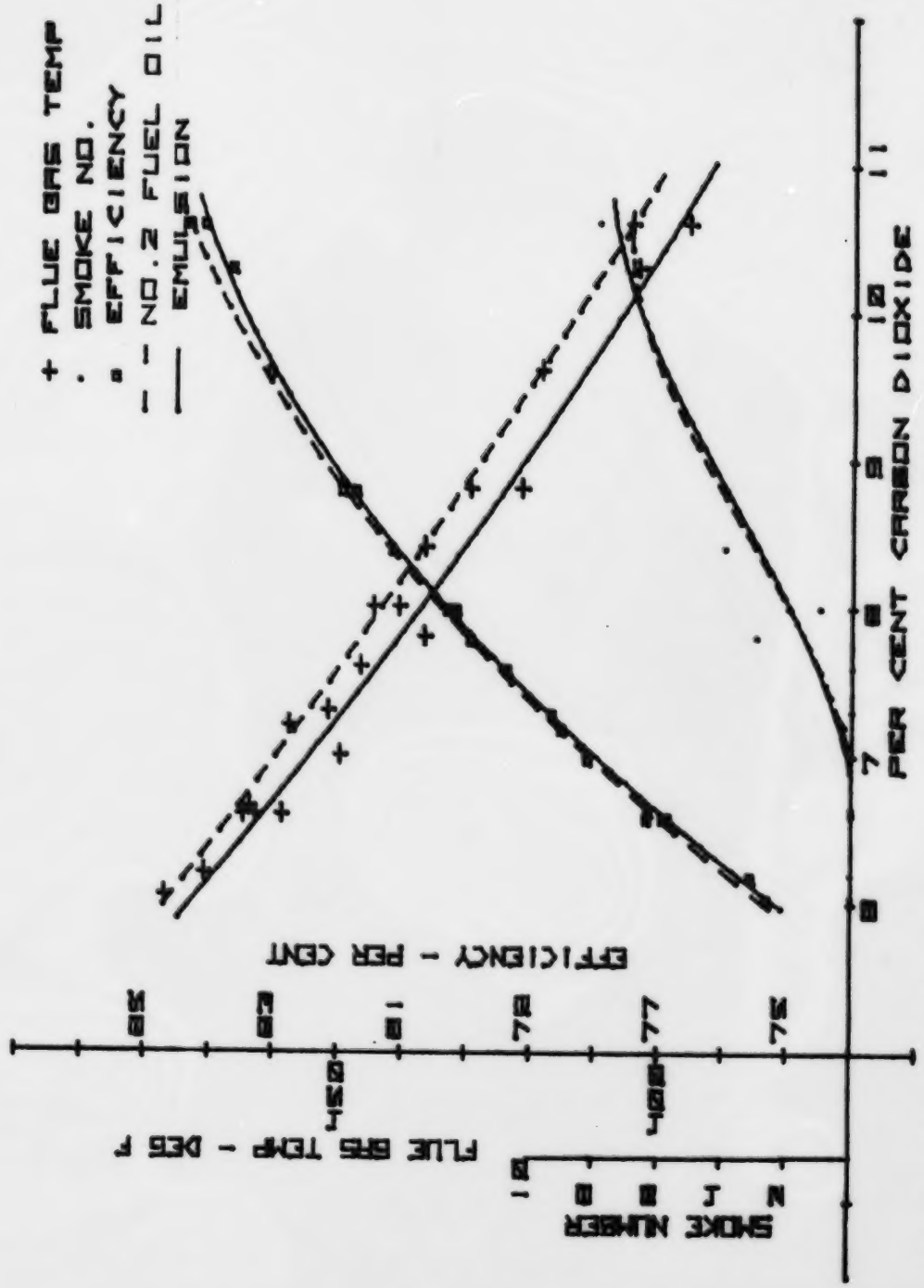

Figure 5. Combustion Performance Profiles with Standard-Head Burner; Emulsion Water Content 7.0 vol %

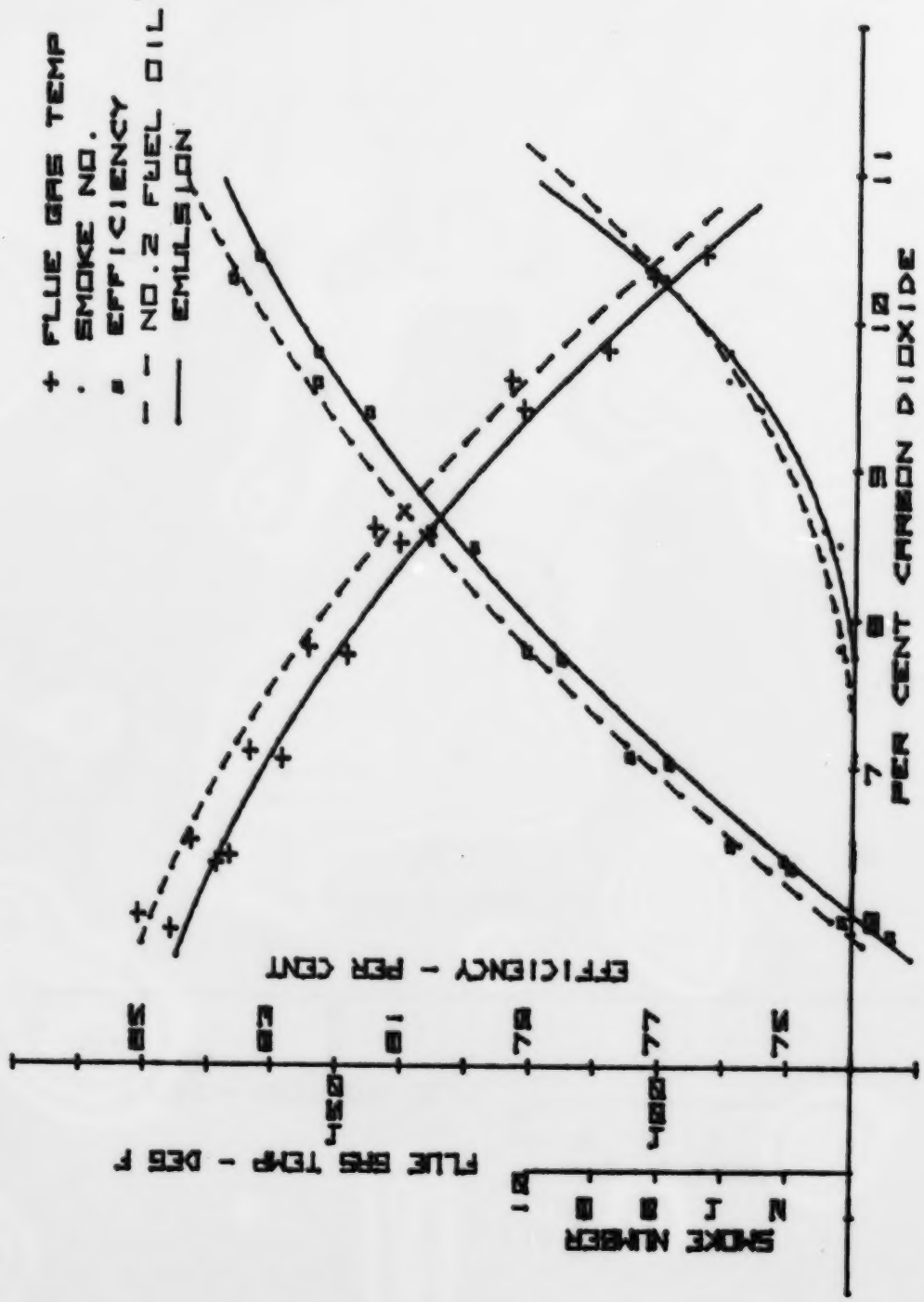

Figure 6. Combustion Performance Profiles with Standard-Head Burner; Emulsion Water Content 10.0 vol %

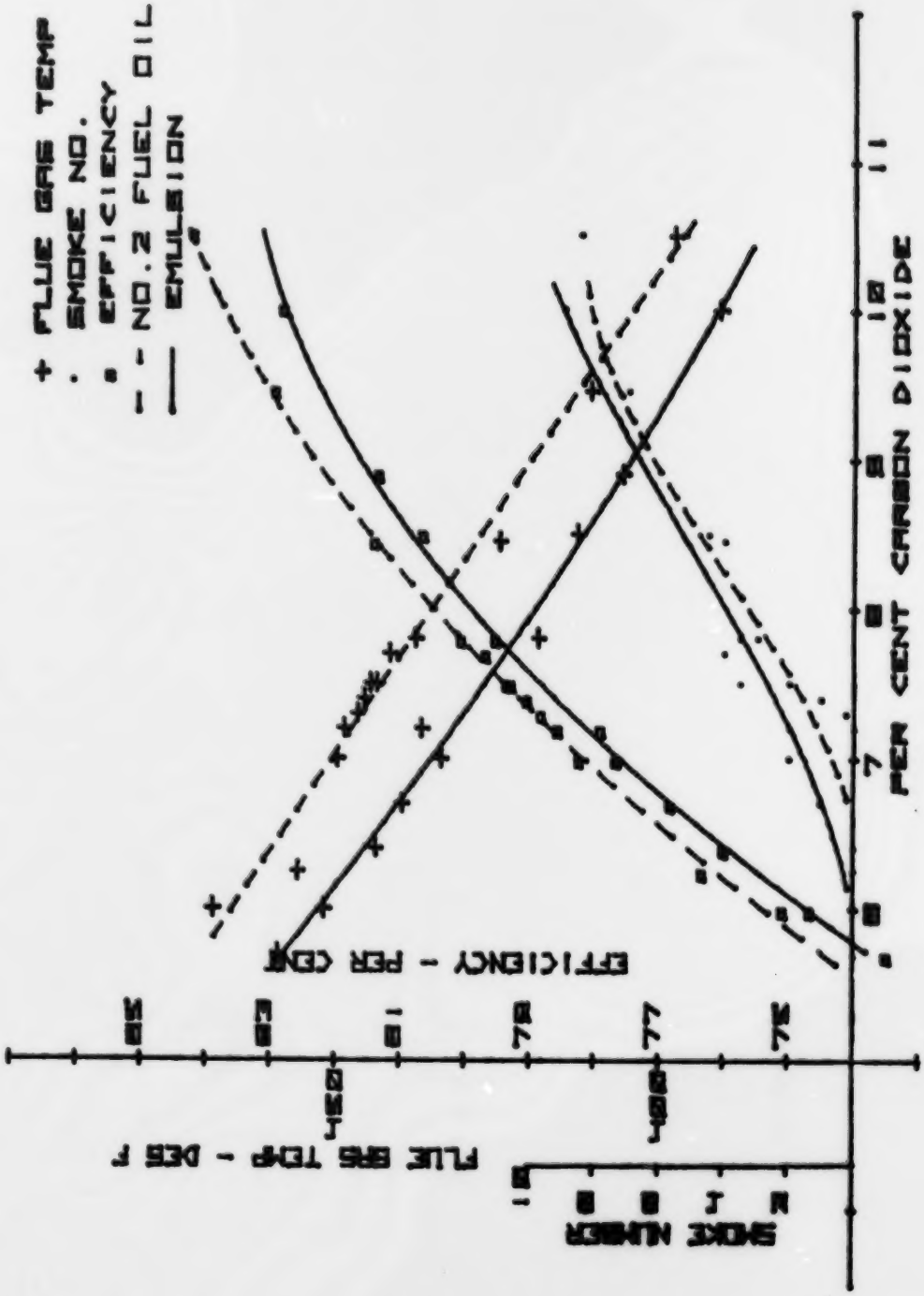

Figure 7. Combustion Performance Profiles with Standard-Head Burner; Emulsion Water Content 15.0 vol %

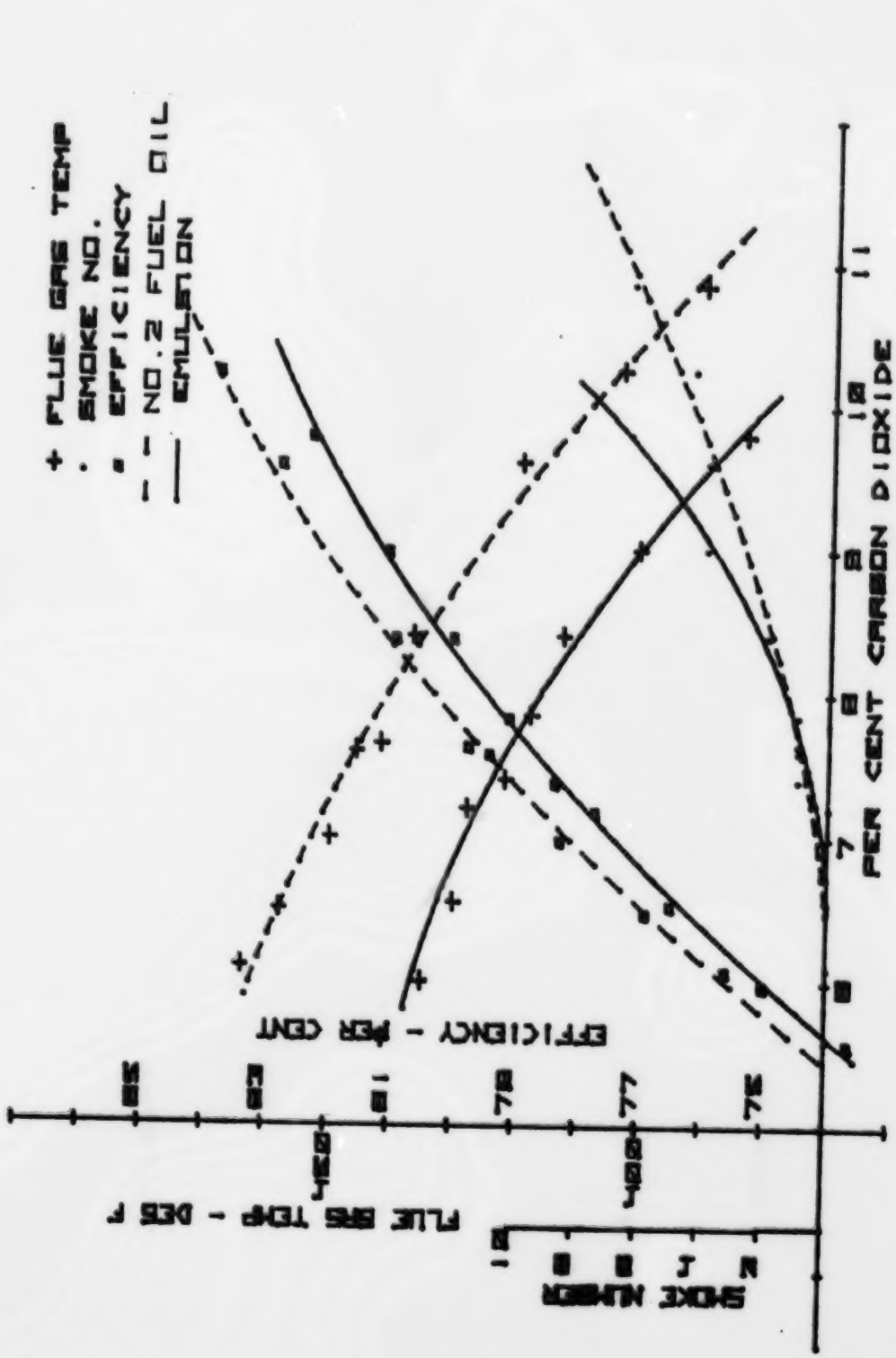

Figure 8. Combustion Performance Profiles with Standard-Head Burner; Emulsion Water Content 20.0 vol %

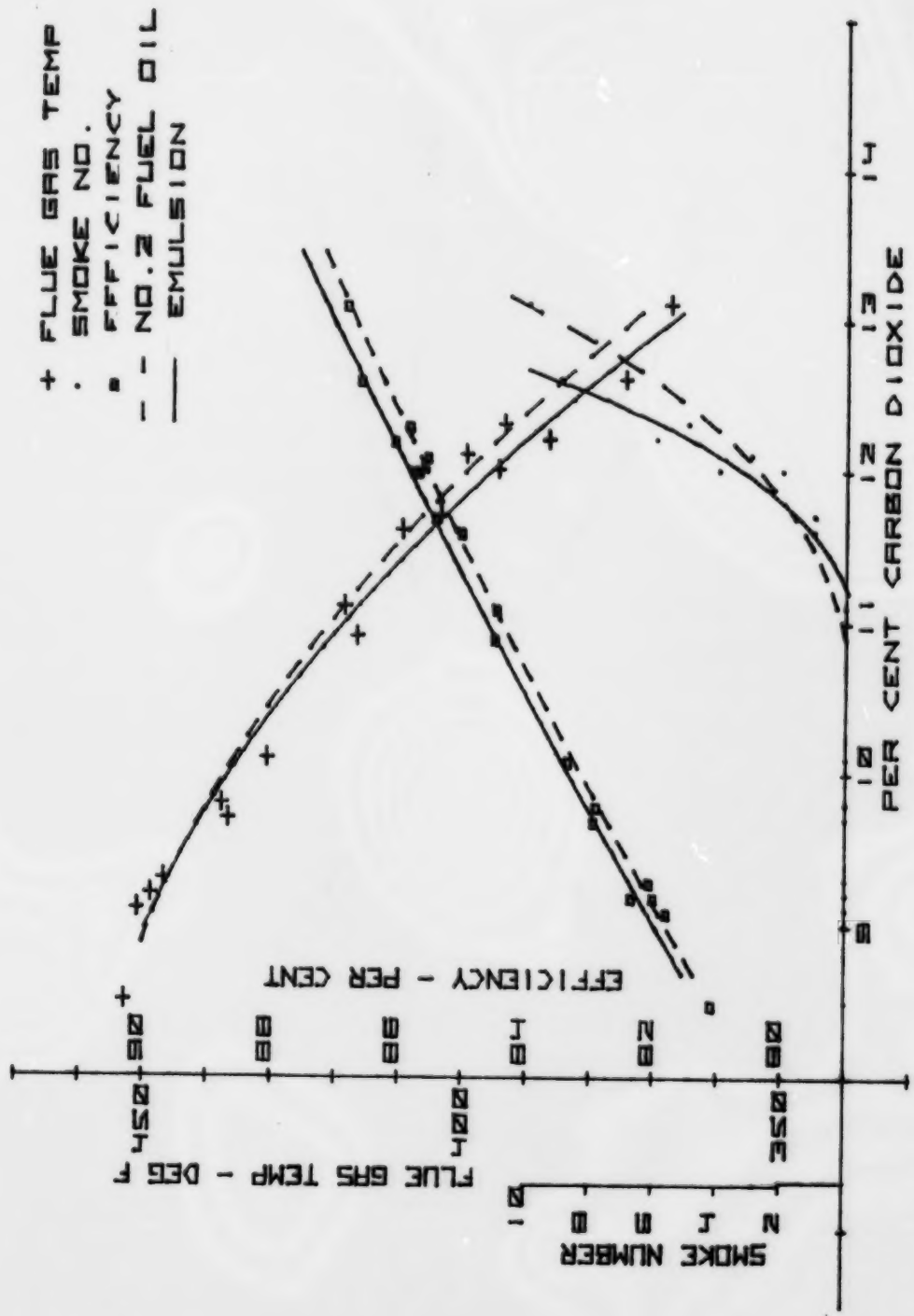

Figure 9. Combustion Performance Profiles with Retention-Head Burner; 4.0 vol % Span 80 with No Water Addition

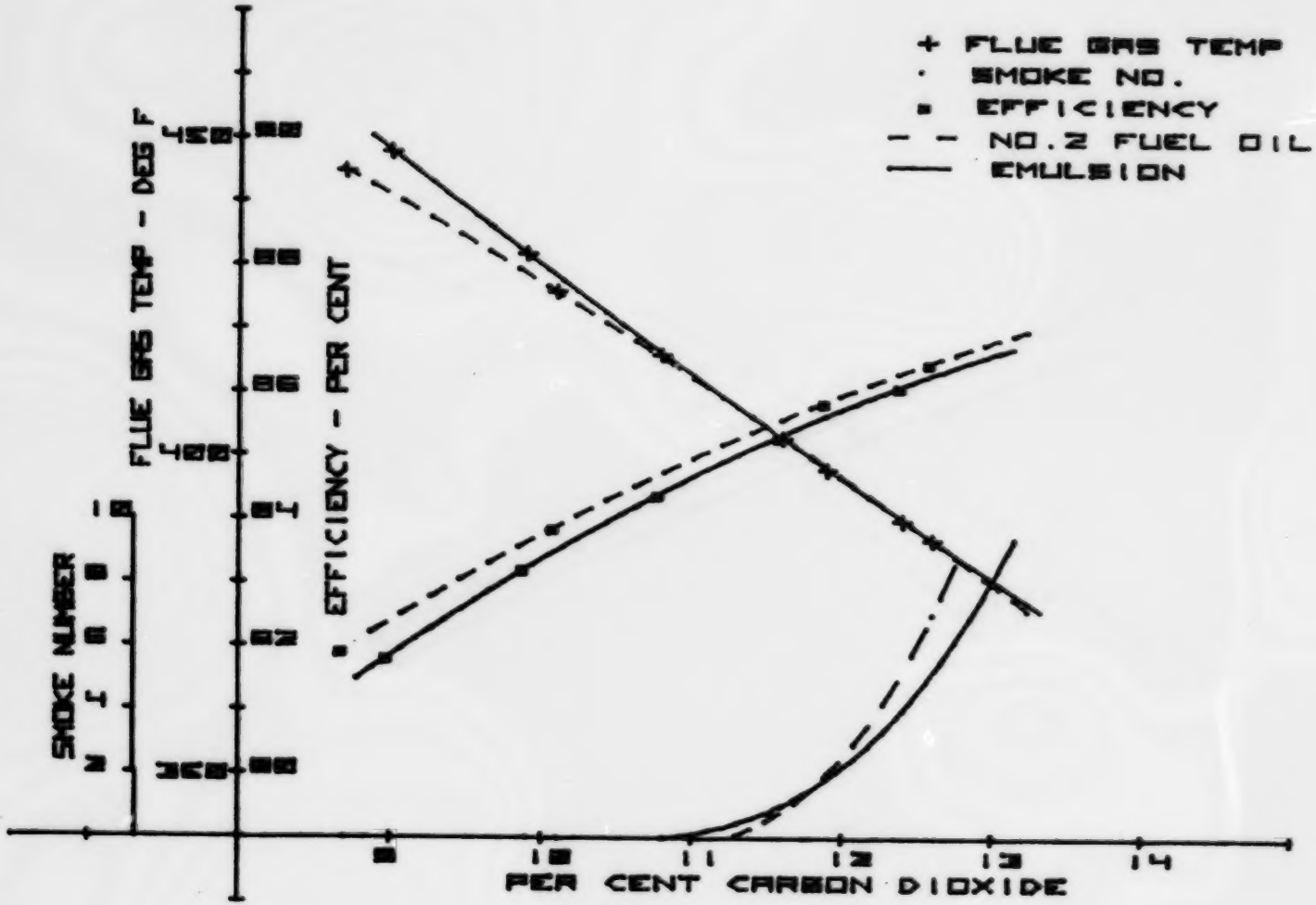

Figure 10. Combustion Performance Profiles for the Retention-Head Burner; Emulsion Water Content 1.0 vol %

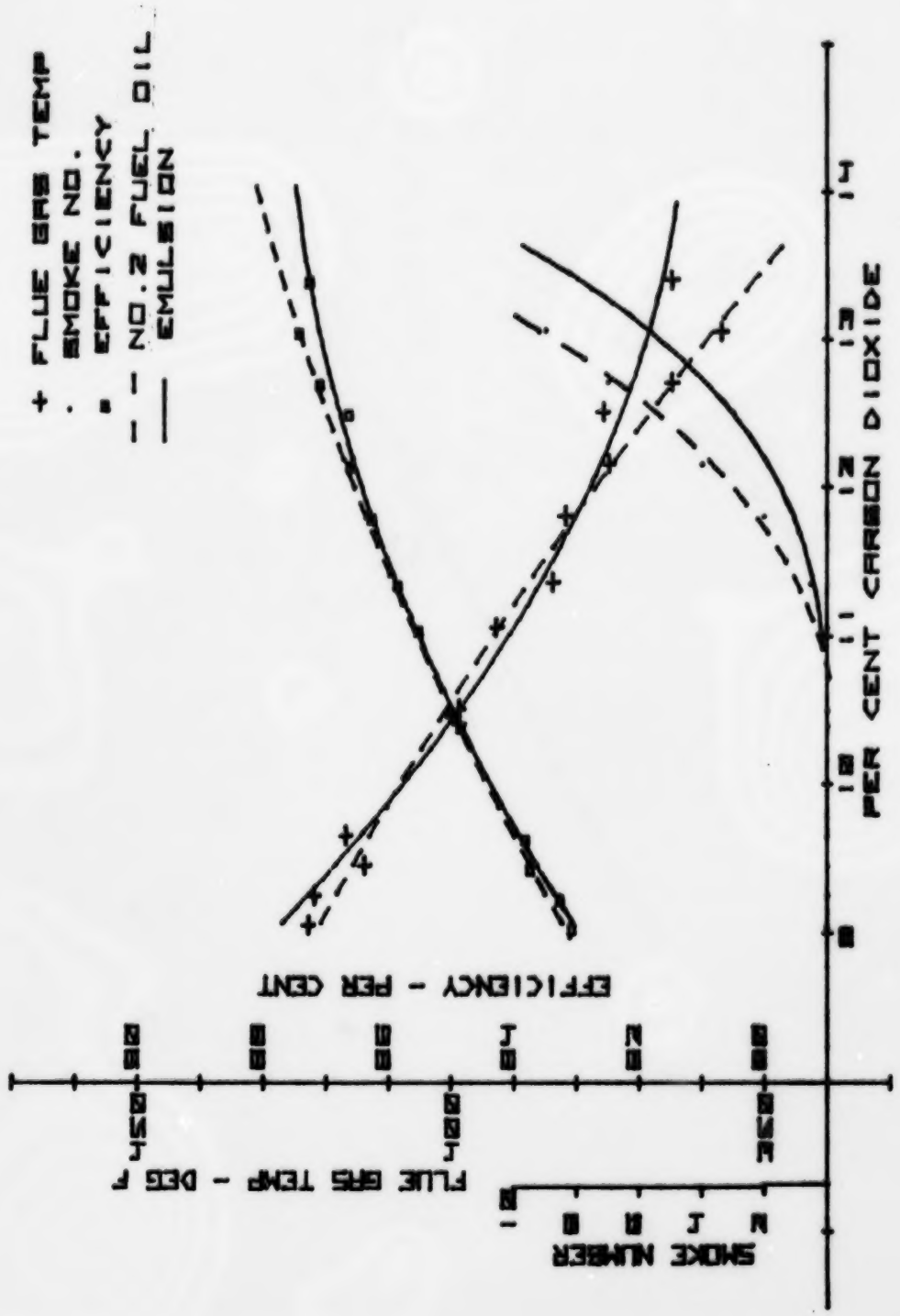

Figure 11. Combustion Performance Profiles with Retention-Head Burners; Emulsion Water Content 2.0 vol %

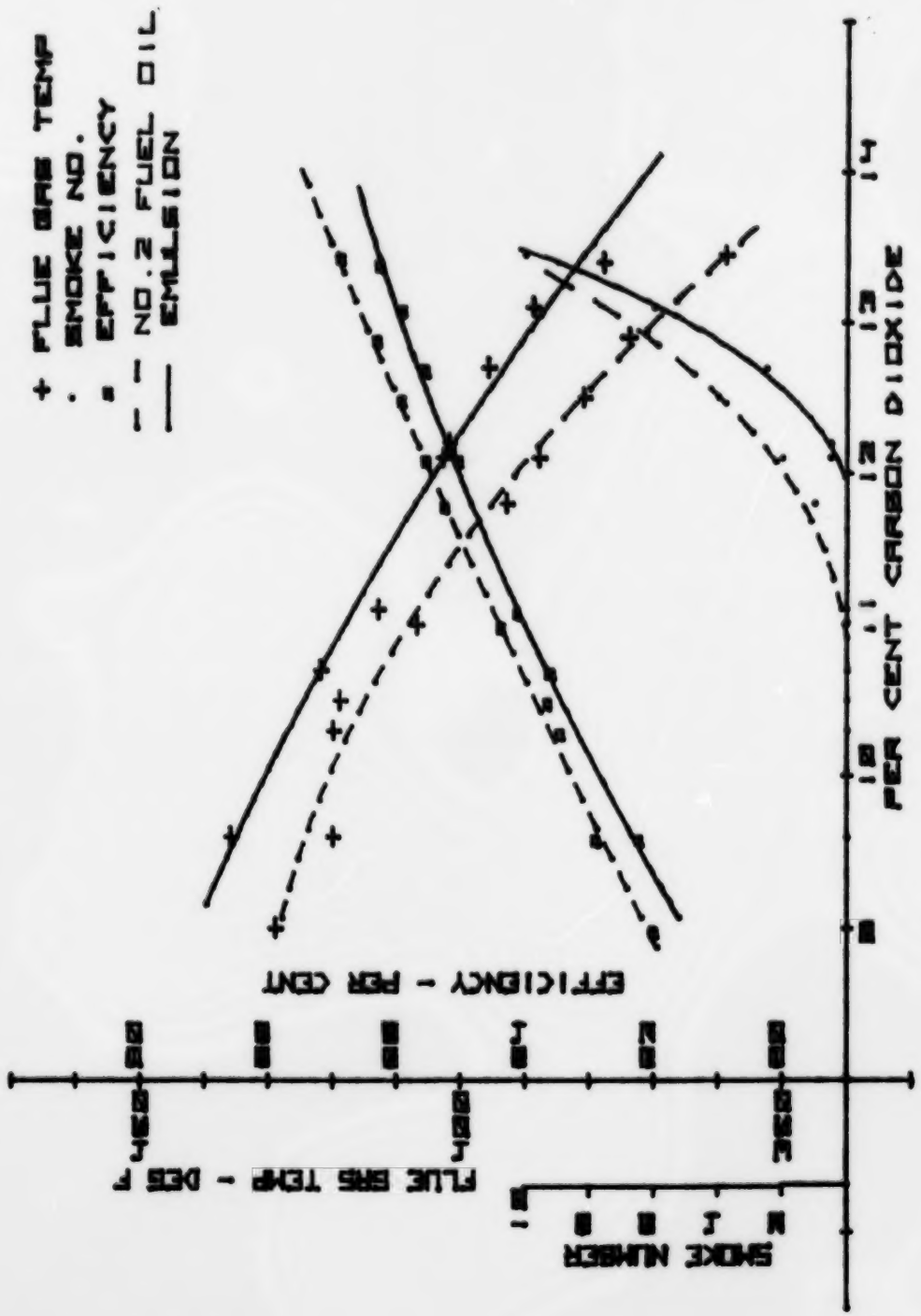

Figure 12. Combustion Performance Profiles with Retention-Head Burner; Emulsion Water Content 3.0 vol %

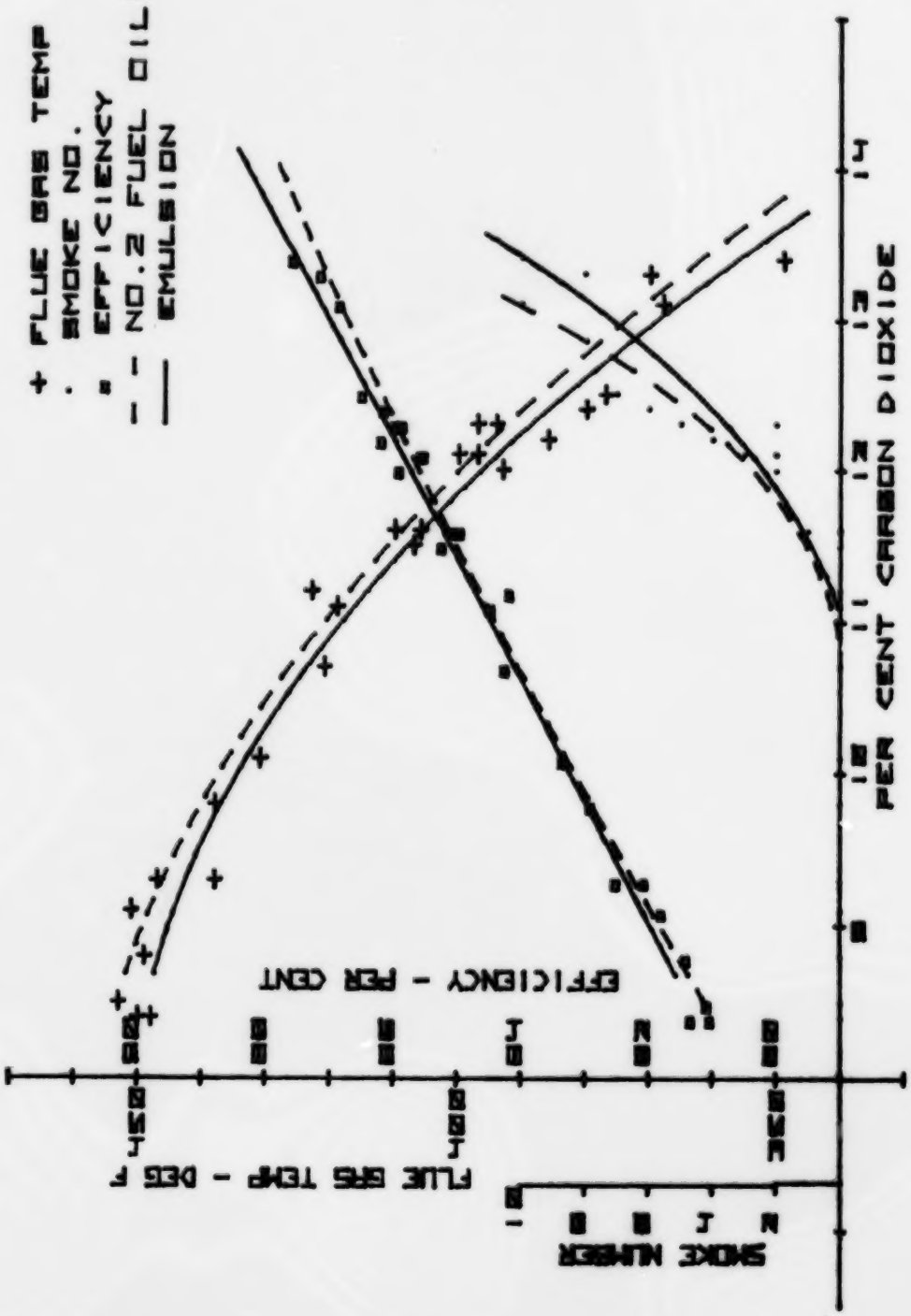

Figure 13. Combustion Performance Profiles Retention-Head Burner; Emulsion Water Content 5.0 vol %

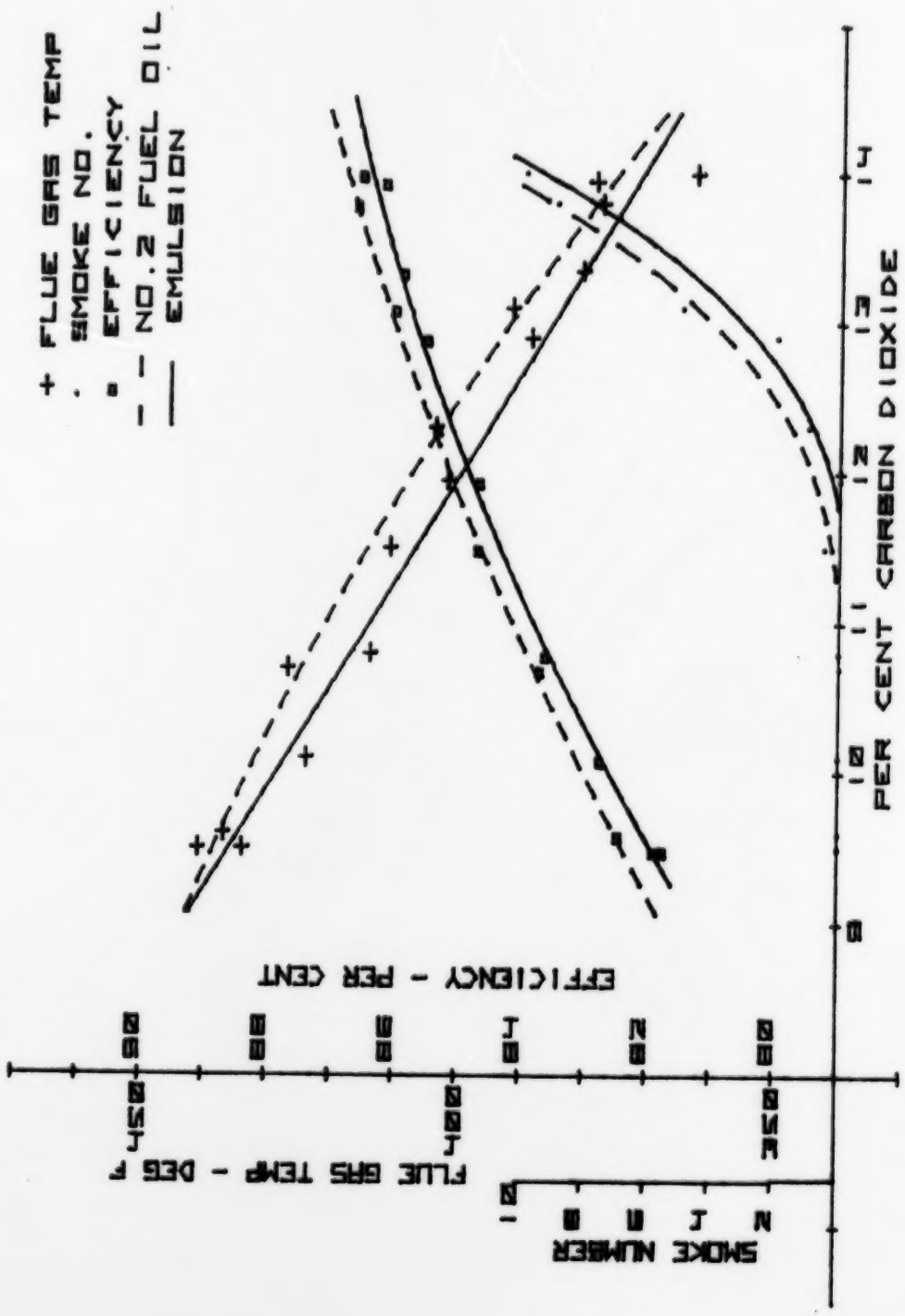

Figure 14. Combustion Performance Profiles for Retention-Head Burner; Emulsion Water Content 7.0 vol %

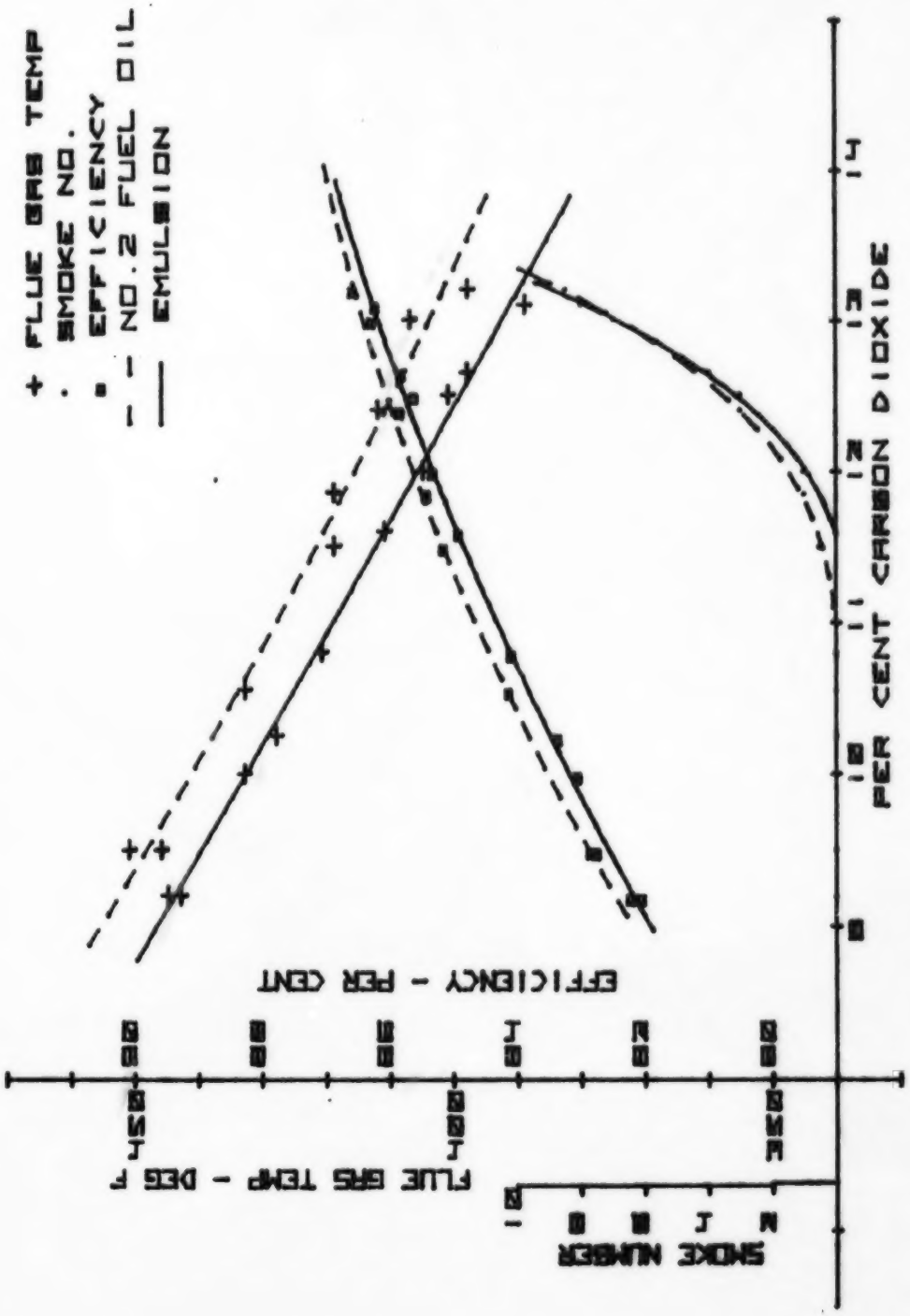

Figure 15. Combustion Performance Profiles for Retention-Head Burner; Emulsion Water Content 10.0 vol %

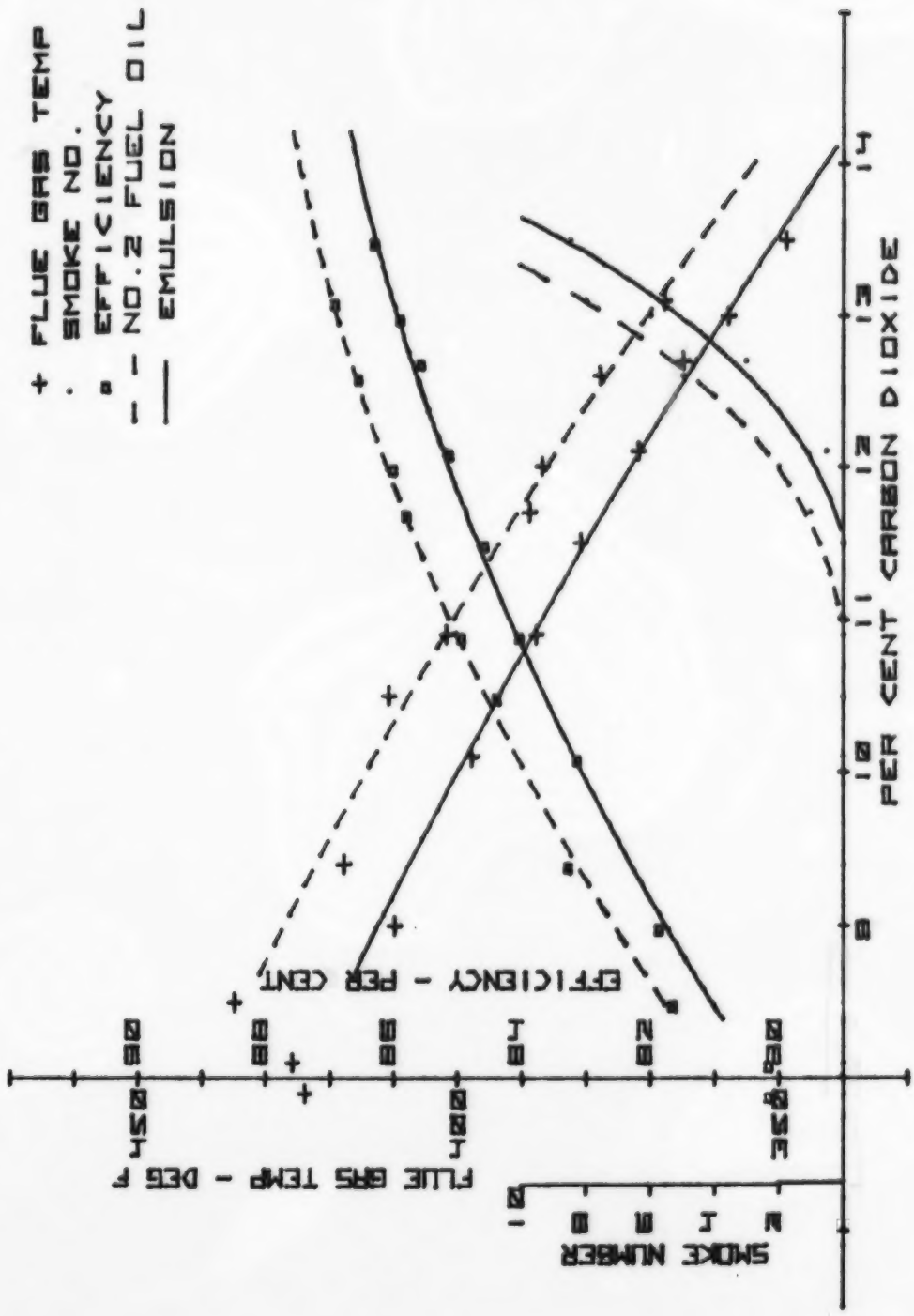

Figure 16. Combustion Performance Profiles for Retention-Head Burner; Emulsion Water Content 15.0 vol %

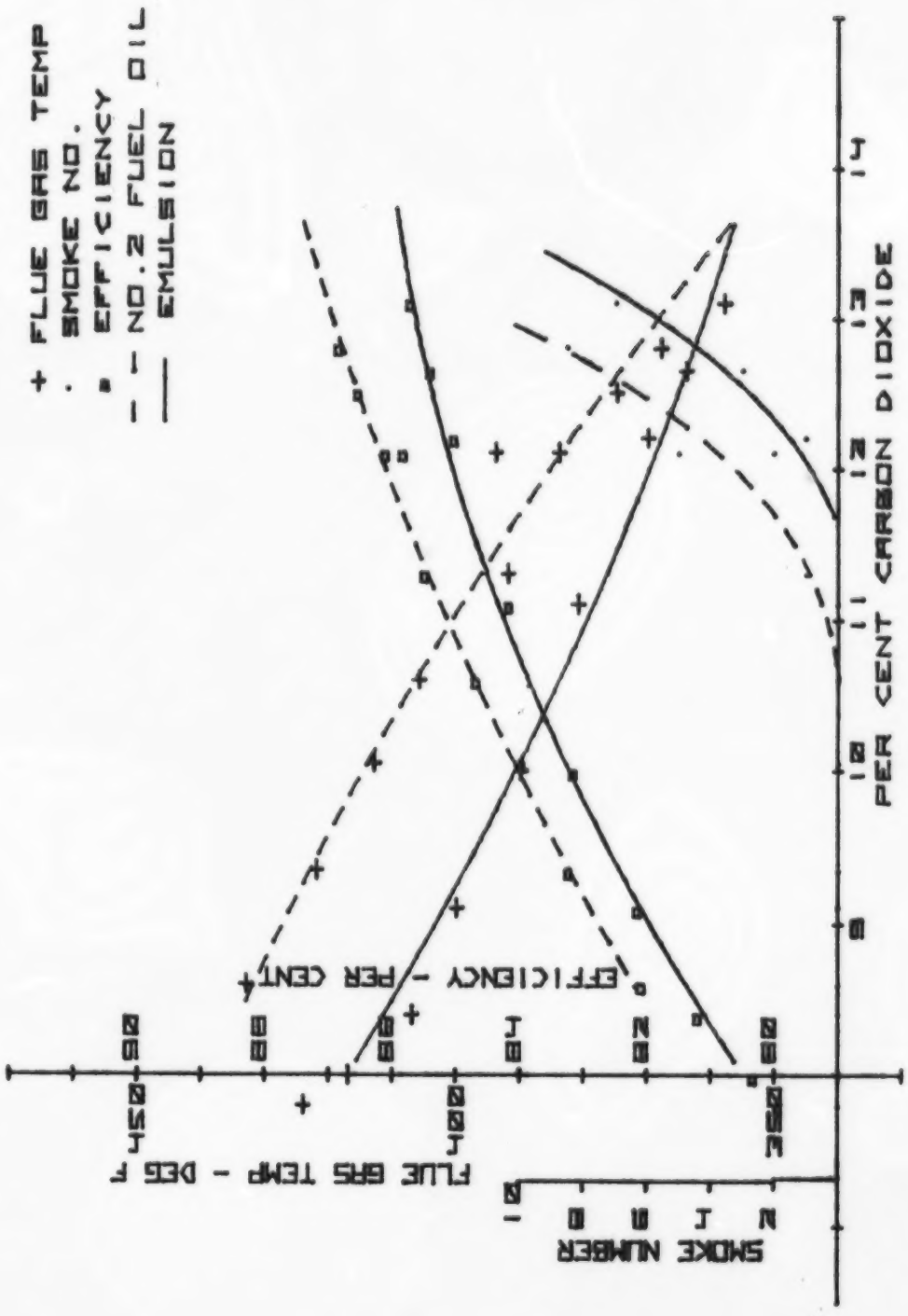

Figure 17. Combustion Performance Profiles for Retention-Head Burner; Emulsion Water Content 20.0 vol %